An Ocean Observing System for Large-Scale Monitoring and Mapping of Noise Throughout the Stellwagen Bank National Marine Sanctuary

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Award Number: *N00014-07-1-1029*
http://stellwagen.noaa.gov/science/passive_acoustics.html

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **An Ocean Observing System for Large-Scale Monitoring and Mapping of Noise Throughout the Stellwagen Bank National**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Cornell Laboratory of Ornithology,Bioacoustics Research Program,159 Sapsucker Woods Road,Ithaca,NY,14850**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

LONG-TERM GOALS

The project goals were to map the low-frequency (<1000 Hz) ocean noise budget throughout the Stellwagen Bank National Marine Sanctuary (SBNMS) ecosystem, identify and quantify the contributing sources of anthropogenic sounds within that ecosystem, and determine whether or not such noises have the potential to impact endangered marine mammals and fishes that use the Sanctuary.

OBJECTIVES

This project represented a high-level, integrative 'bench mark' study aimed at characterizing the marine acoustic environment and the health of an urbanized, productive ecosystem, SBNMS. The primary products were a suite of tools designed to be transferable to other ecological regions and an extensive database specific to the project. These included both mechanisms for data collection and analysis as well as a conceptual framework for integrating and interpreting the scientific results.

APPROACH

Data from arrays of Marine Autonomous Recording Units (MARUs), deployed since December 2007 under this NOPP grant gathered low-frequency acoustic data within the sanctuary for a 30 month period, ending May 2010. In previous years we focused on building tools and representing the communication space of North Atlantic right whales and the impact thereupon of AIS vessels. In FY11 we focused on streamlining our tools so that they could process large numbers of animals and vessels, adding fishing and whale watching vessels to the noise calculations in addition to AIS vessels and lastly, detecting and localizing multiple species of vocally active baleen whales (North Atlantic right whale, fin, humpback and minke whales). Data on the distributions and acoustic behaviors of ships and the four species of baleen whales were merged to investigate the potential for ocean noise to mask each species and different call types within species. This study was co-managed by Cornell University Laboratory of Ornithology's Bioacoustics Research Program (Cornell), NOAA Fisheries' Northeast Fisheries Science Center (NEFSC) and NOAA NOS's Stellwagen Bank National Marine Sanctuary (SBNMS). For Cornell, Dr. Christopher Clark, Dr. Peter Dugan and Dimitri Ponirakis focused on streamlining the analysis tools for quantifying and mapping ocean noise, communication space and communication masking. For NEFSC, Dr. Sofie Van Parijs, Dr. Danielle Cholewiak and Denise Risch, as well as NOAA-sponsored Scholars and interns are involved in the whale and noise analyses. For SBNMS, Dr. Leila Hatch and Michael Thompson were involved in analyses of the AIS, fishing vessel and whale watching data.

WORK COMPLETED

From December 2007 to May 2010, consecutive arrays of MARUs were deployed to record continuously at 2-10 kHz sampling rates for approximately 90 days at a time, in geometries designed to detect and localize vocally-active whale and fish species within sanctuary waters. Continued efforts during 2010-11 had three main foci: 1) develop an automated analysis framework in which multiple data layers can be combined to calculate Communication Space and Masking Metrics (CSM) for marine animals; 2) implement these tools to evaluate CSM for multiple mysticete species that are vocally active within the SBNMS; 3) integrate fishing vessel tracks and whale watching tracks into CSM alongside AIS vessels.

Four mysticetes species occur annually within the study area, including North Atlantic right, humpback, minke, and fin whales. For fin and minke whales, one-week periods representing their peak occurrence were chosen for analysis. For North Atlantic right whales, two one-week periods were chosen for analysis, representing periods when different call types, the up-call or gunshot were more predominant. For humpback whales, two one-week periods were also chosen, representing a change in predominant vocalization type from social calls to song. The resultant dataset included six weeks, representing four species and six call type categories (Table 1).

SEDNA, a Matlab-based, data-integration package was developed and implemented for this project (Dugan et al. 2011). MARU sound data were processed to calculate RMS received levels in 1/3rd octave bands. An ambient noise tool was developed to regress background noise levels against wind data obtained from local oceanographic buoys (GMOOS A01 & NDBC 44013). The resulting relationship was used to generate the present-day ambient noise level grid (*PrA1*) for each analysis week.

For each species, distribution and 2-D movements of simulated animals (animats) were generated utilizing the AIM model (Ellison et al. 1999), and were subsequently imported into SEDNA. A tool was developed to spatially propagate the calls of individual vocalizing animals onto a grid of receivers, using a 17 log*r transmission loss model. Later this year, these results will be rerun using the Bellhop transmission loss model once it is integrated into SEDNA.

Multiple vessel categories were incorporated into the current effort, including whale-watching, fishing, and AIS-tracked vessels. SEDNA allows for the integration of each of these vessel layers separately, based upon differences in underlying data structures. For AIS-tracked vessels, event file and track figures are generated, and source levels (SL) were calculated for those vessels that passed within 3 km of an individual MARU (Figure 1). Positional data for fishing vessels were incorporated using Vessel Monitoring System information, and simulated tracks for whale-watching vessels were generated based on known GPS data. Vessel animat files were created by recording the details of all vessels that occur within each time interval over the period of interest. Source levels were calculated for individual vessels when possible and these data were used to assign SLs to similar vessels with unknown SLs. Layers representing

cumulative noise levels from all tracked vessel types (*PrA2*) were generated by combining appropriate grids for each analysis period.

SEDNA was used to combine these data layers to generate predicted noise surfaces throughout greater Massachusetts Bay, gridded into 1 km^2 cells, for each analysis period and band-level of interest. CSM metrics (signal excess and masking) were calculated for each species and call type based on the combination of appropriate layers for each period (Clark et al. 2009). A CSM GUI was developed to spatially visualize instantaneous sound received levels, signal excess for individual senders, noise level exposure, as well as the temporally varying CSM metrics (Figure 2). An overall index of communication masking (Clark et al. 2009) was calculated for each species to compare the effects that various forms of vessel activity have on the communication space for species with vocalization characteristics.

RESULTS

Six weeks between January 2008 and December 2009 were evaluated for presence of calling activity for one of four different mysticete species. Data evaluation included both manual browsing and the use of automated detectors. Presence or absence of calling activity was summarized in 10-minute bins for each of the days in the selected weeks. Overall average percentage of 10-minute bins with vocal activity ranged from 41.9% for humpback social sounds to 92.9% for fin whale 20-Hz pulses.

Source levels for each of the call types were calculated based on RLs of calls from a subset of animals that were located within or near the MARU arrays. A transmission loss model of 17 log*r was used to estimate source level based on the received level of the signal and the distance of the animal to the MARU. Right whale gunshots had the highest SL (206.1 ± 4.5 dB re: 1µPa), while humpback whale social sounds had the lowest SL (162.3 ± 9.9 dB re: 1µPa; Table 1).

For each species, the numbers of animats used in the models as well as their distributions were determined based on long term visual sighting data collected by the NEFSC (http://www.nefsc.noaa.gov/read/protspp/mainpage/surveys/index.html). When appropriate, animat distributions were bounded within a subset of the study area to better reflect a species distribution. Numbers of animats ranged from 3 (Week 1, January 2008, right whales) to 89 (Week 2, March/April 2009, right whales; Table 1).

Vessel activity varied greatly among the 6 analysis weeks. Numbers of large vessels carrying AIS carriage A transponders ranged from 53 (Week 1, January 2008) to 93 (Week 4, July 2009). Approximately 120 fishing vessels were estimated to be active in the study area in each week; whale-watching vessels were only active in July (29 vessels) and October (5 vessels). Average calculated source levels for each of the vessel types ranged from 135-156 dB in the $1/3^{rd}$- octave bands of interest for the whale-watching and fishing vessels, and from 140.4 –193.5 dB in these same bands for AIS vessels.

The effect of different vessel types on the communication space (CSM) for all species was analyzed both separately and collectively. When compared to CSM available under historic ambient noise conditions (~1950's, prior to significant increases in levels of commercial shipping traffic), right whale gun shots were found to have lost, on average, 19% of their CSM , compared with 78% for up-calls, 98% for minke whale pulse trains and 89% for humpback whale social sounds. The numbers for fin whales and humpback whale song are still being analyzed. Figure 3 shows the difference in communication masking for one species (right whale) in two different behavioral/vocal contexts. Note that right whales suffer a greater loss of communication space while producing up call vocalizations than they do while producing gun shots. The percent of CSM lost was influenced by presence or absence of each vessel class. As expected, fishing and whale-watching vessels had a much lower impact on communication space loss when compared to AIS vessels. As a word of caution, the numbers presented above are preliminary, not all weeks are finalized and we still need to run these through the Bellhop propagation model. This will better reflect sound propagation within the study area as demonstrated by our previous transmission loss work in previous years on this project, as well as allow comparisons to other studies. However, these are the types of metrics and comparisons that we will have by December 2011. Additionally, for this analyses we are calculating the average CSM across individual "senders", and not looking at masking at the population level.

Table 1. Dates and vocally-active species for each of the six analysis weeks. The number of simulated whale animats per day were chosen based on visual sighting data. Vocalization characteristics were obtained through analysis of MARU recordings. Source levels are RMS and reported in dB re: 1µPa. Three call types were chosen to characterize humpback whale song and social sounds; only one is reported here.

Week #	Date Start	Date End	Species	# Whale Animats/ Day	Call Type	1/3-Octave Band Center Freq.	*n*	SL (dB)	SD (dB)
1	1/24/2008	1/30/2008	Eg	3	Gunshots	400	83	**206**	**4.5**
2	3/28/2009	4/3/2009	Eg	89	Up-calls	160	353	**165**	**3.5**
3	4/12/2009	4/18/2009	Mn	6	Song	80	140	**170**	**2.9**
4	7/16/2009	7/22/2009	Mn	50	Social	80	20	**164**	**5.5**
5	10/3/2009	10/9/2009	Ba	9	Pulse train	125	87	**163**	**3.9**
6	12/23/2009	12/29/2009	Bp	4	20Hz pulse	20	215	**180**	**5.4**

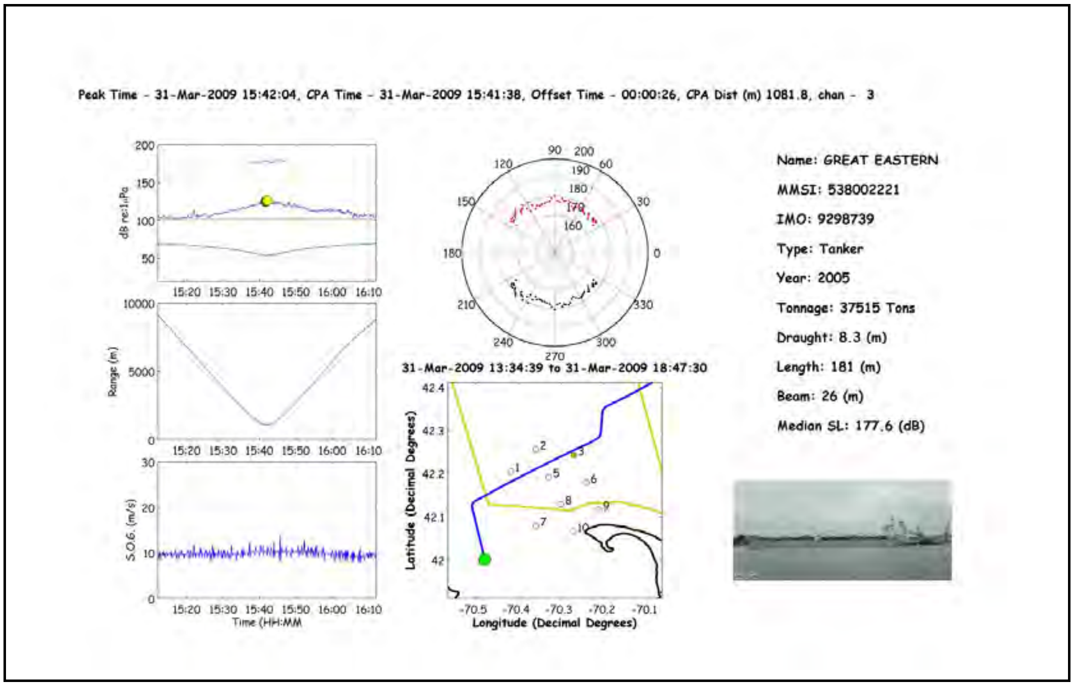

Figure 1. An example of SEDNA-generated event data for a single AIS-tracked vessel. Along the left column, the received level (dB rms re: 1µPa) on a single MARU, range to the MARU, and speed over ground of the vessel are recorded. In the middle column, the relative bearing between the vessel and the MARU at the time of closest approach and track of the vessel relative to the MARU array are shown, and publicly-available data about the vessel are shown in the right column.

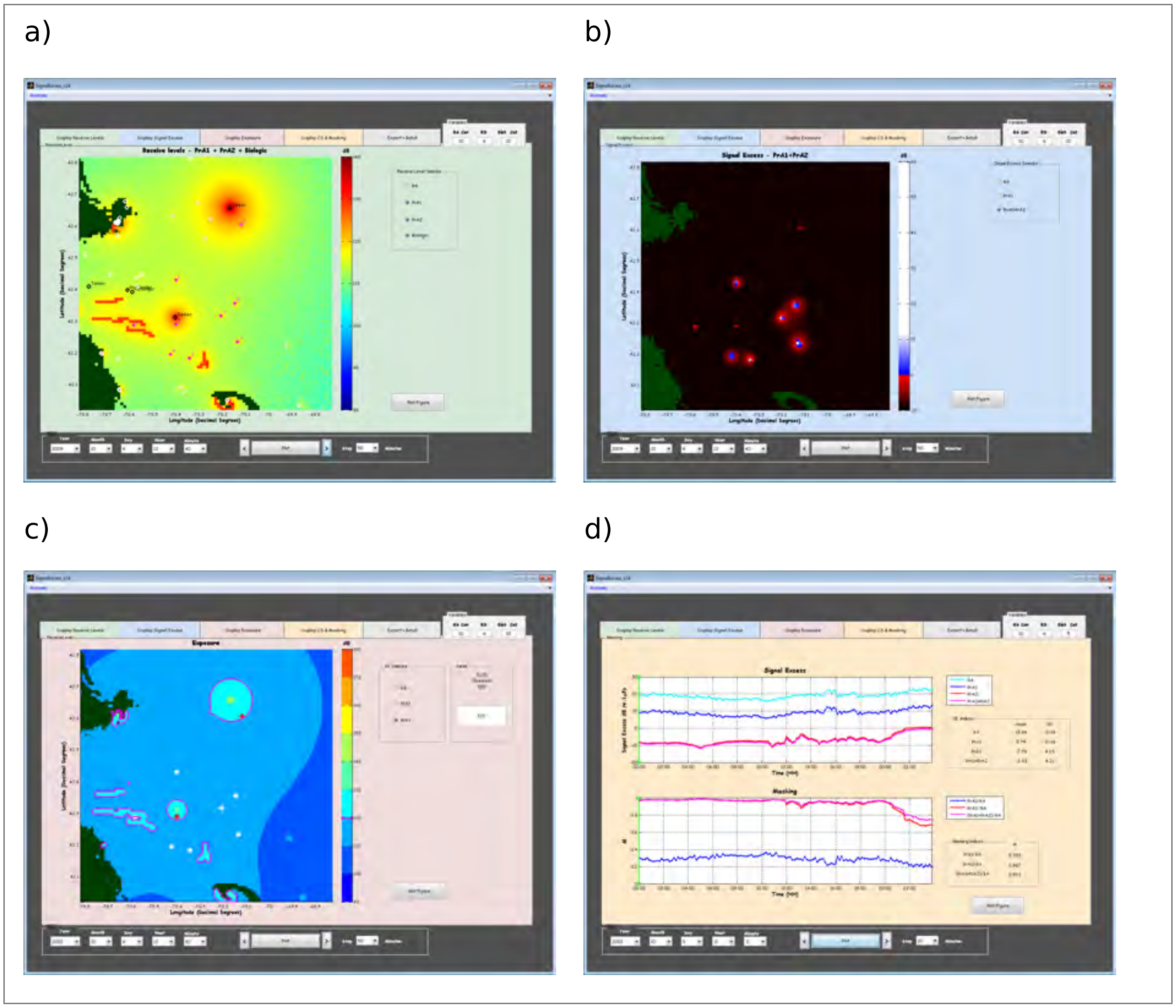

Figure 2. An example of the SEDNA-based visualizations of CSM metrics. a) Summed received levels from AIS-tracked, fishing, and whale-watching vessels, Minke Whale pulsed calls, and ambient sound. b) Spatial view of signal excess for individual calling whales, based on the anthropogenic and ambient noise displayed in (a). Values below zero indicate that an individual cannot be heard above the background noise in this space. In this example, all individuals are acoustically isolated from one another due to background noise conditions. c) Areas where anthropogenic sound exposure exceeds 120 dB are mapped, showing individual whales that would be exposed at or above this noise level. d) Time-series plot of Signal Excess, Communication Space and Masking Metrics. In this example, noise conditions result in over 90% masking for most of the day.

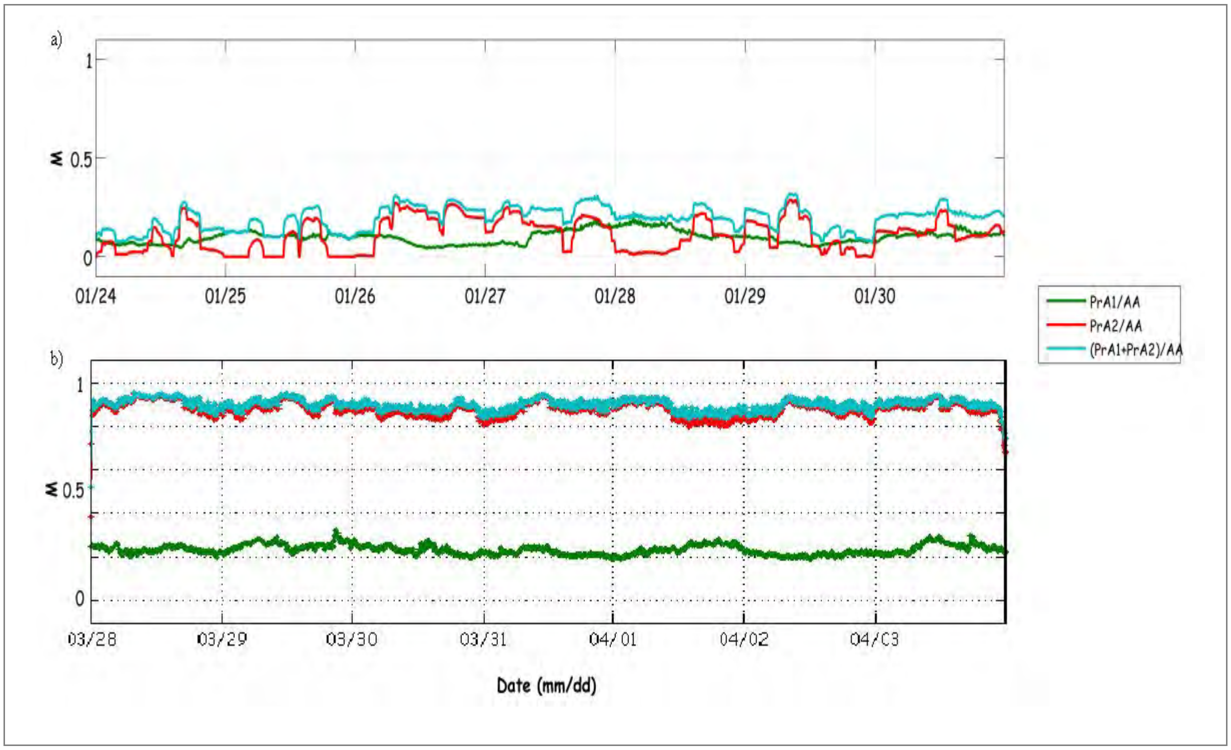

Figure 3. Index of communication masking (M) for North Atlantic right whales while a) producing gunshots and b) producing up-calls. The x-axis displays the dates, and the y-axis displays the Masking Index on a scale from 0 to 1. The green line indicates the level of masking under current ambient noise conditions *(PrA1)* as compared to historic conditions *(AA)*, the red line indicates the level of masking induced by vessel traffic *(PrA2)*, and the blue line indicates the level of masking from both ambient and anthropogenic noise combined *(PrA1+PrA2)*. Source levels for up-calls are nearly 40dB lower than for gunshots, therefore communication masking is much higher when right whales are producing up-calls.

IMPACT/APPLICATIONS

National Security

The Stellwagen NOPP Project produced a suite of transferable tools for assessing contributions from several sources of noise to an underwater noise budget. These tools are valuable for assessing and contextualizing the place-based environmental impacts of defense-related activities, including training range development, sonar use, and high-density vessel activities. Efforts are currently underway to streamline and improve the user interface for these tools.

Quality of Life

By describing and assessing the impacts of changes in the acoustic environment for marine animals over biologically-relevant scales, this project will better inform managers and the general public regarding how best to minimize and/or mitigate the costs of human activities that introduce noise into the coastal environment. Tools created as part of the Stellwagen NOPP can be used by various stakeholders (i.e., governmental agencies, ocean user groups, environmental consultants, environmental advocacy organizations, and private citizens) to ensure that chronic, sub-lethal anthropogenic impacts associated with human activities (i.e. shipping noise) are included in national, regional and international marine spatial planning initiatives.
A current effort within NOAA heavily relies on the tools developed from this and other related projects to map the sound field throughout the US EEZ and provide these metrics and maps alongside existing and improved density models of cetaceans.

Science Education and Communication

Two publications one on communication masking of North Atlantic right whales and one on humpback whale seasonal calling rates are under review. Several others will be forthcoming over the next year, including a manuscript on transmission loss for SBNMS study area. Project PIs will highlight this work at the North Atlantic Right whale consortium meeting (New Bedford, MA; November 2-3 2011), and the upcoming 19th Biennial Conference on the Biology of Marine Mammals (Tampa, FL; November 27 to 2 December 2011;.

TRANSITIONS

Quality of Life

Methodologies being developed for this project were also used to evaluate impacts associating with the construction and operation of two offshore liquefied natural gas terminals adjacent to the SBNMS. As the contractor responsible for evaluating the acoustic impacts of these terminals and as a result of this NOPP-funded research, Cornell continues to develop new ways of calculating and articulating the contributions of multiple types of noise sources to the noise budgets in the area. Additional contracts to provide passive acoustic monitoring in Arctic waters coincident with seismic exploration for oil and gas resources have also received the benefit of these NOPP tool developments.

Science Education and Communication

One scientific paper on North Atlantic whale occurrence and seasonal distribution has been accepted for publication in Endangered Species research, The sanctuary's website was supplemented to provide information on the project and noise in the marine environment (http://stellwagen.noaa.gov/science/passive_acoustics.html). Between October 2010 and September 2011, the Stellwagen NOPP project was highlighted in several public media pieces.*National Geographic* magazine ran an article entitled "Quieting Noisy Oceans" January 2011 that addressed this work. An article in Scientific American entitled "Noise Reduces Ocean Habitat for Whales" highlighted communication masking research in the sanctuary, including a video of sound in the sanctuary (October) http://www.scientificamerican.com/article.cfm?id=noise-reduces-ocean-habitat-for-whales. An article on the website Scienceline.org on right whales, acoustic impacts and sanctuary research addressed this work http://scienceline.org/2011/06/looking-for-admiral/ . New Scientist published a story that appeared in June on ocean noise pollution, predominantly focused on shipping, which highlighted the work in the sanctuary http://www.newscientist.com/article/mg21028165.200-software-simulator-tracks-undersea-noise-pollution.html. Project PIs highlighted this project's results in multiple forums, including the 3rd Symposium of the Acoustic Communication of Animals, which included a workshop on Acoustic Ecology (Ithaca, NY; 1- 5 August 2011) and the Detection, Classification and Localization workshop (Mt. Hood, OR; 22 – 25 August 2011).

RELATED PROJECTS

The Stellwagen NOPP Project is related to a database development project, a cumulative impact mapping project, collaborative dialogue with the population modeling project (http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammal-Population.aspx)and a NOAA working group project aimed at mapping the sound field and cetacean densities and distribution throughout the US EEZ. Sofie Van Parijs is working on the realization of an acoustic database for use by federal agencies and is PI on a recent NOPP database grant and together with Chris Clark is collaborating closely with a recent NOPP OBIS-SEAMAP grant awarded to Pat Halpin. The Massachusetts Oceans Partnership is engaged in mapping the annual cumulative impacts of human activities on the marine environment from the Commonwealth's shoreline to the boundaries of the US Exclusive Economic Zone. Through collaboration with researchers based at the National Center for Ecological Synthesis and Analysis (NCEAS; Santa Barbara, CA), information from the Stellwagen NOPP project is informing a preliminary representation of noise from large commercial shipping in these maps.

The NOAA Marine Mammal and Sound Working Groups (Underwater Sound-field Mapping and Cetacean Distribution and Density Mapping)represent a NOAA led effort to develop geospatial products and tools for representing human-induced noise and important areas of

cetacean activity throughout the US EEZ. These efforts integrate expertise and support from multiple agencies within the USG as well as multiple universities and private consulting companies. Several of the PIs on this project are leading and participating in this effort and the experience gained through this NOPP project is and will continue to provide guidance for integrating information on noise and cetacean activity and interpreting the results for management.

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